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# PATENT APPLICATION TRANSMITTAL LETTER

ATTORNEY'S DOCKET NO.
13DV13386

TO THE ASSISTANT COMMISSIONER FOR PATENTS:

Transmitted herewith for filing is the patent application of
RUBEN E. FAIRMAN

(Inventor)

For -----METHODS AND SYSTEMS FOR GENERATING PROFILE CURVES OF SOLID MODELS-----

(Title of invention)

JC675 U.S. PTO 09/532977 03/22/00

Enclosed are:

☒ 3 sheets of ☒ formal ☐ informal drawing. ☐ Please file concurrently with

☐ an assignment of the invention to **GENERAL ELECTRIC COMPANY**

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|---|---|---|---|---|
| TOTAL CLAIMS | 20 - 20 = | 0 | X $18.00 | $0.00 |
| INDEPENDENT CLAIMS | 3 - 3 = | 0 | X $78.00 | $0.00 |
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GEAE (12/99)

# METHODS AND SYSTEMS FOR GENERATING PROFILE CURVES OF SOLID MODELS

## BACKGROUND OF THE INVENTION

This invention relates generally to generating profile curves and, more particularly, to systems and methods for generating two-dimensional profile curves of three-dimensional solid models.

Geometric models of components are often created with computer aided design (CAD) programs to enable a user to view a component in a variety of orientations. Often two-dimensional cross-sectional representations of such components are used by various CAD-dependent processes downstream from the CAD program including computer aided engineering (CAE) analysis, computer aided manufacturing (CAM) and drafting. Specifically, with respect to CAE analysis, two-dimensional CAE analysis often provides results comparable to full three-dimensional analysis, but requires less computational intensity and less time than three-dimensional analysis. Furthermore, with respect to CAM operations, tooling-paths are programmed in two-dimensional planes. Accordingly, two-dimensional tooling-paths include only a maximum revolved profile of the component in a two-dimensional plane which is simplified in comparison to a profile of the component in a three-dimensional definition.

Known profile curve generators use a plurality of intersecting planes to create two-dimensional representations of three-dimensional solids. The intersecting planes are extended through the three-dimensional solid at a plurality of angles disposed about an axis of rotation of the three-dimensional solid. Each intersection of the solid produces a set of curves at a given angle relative to the axis of rotation. The different sets of intersecting curves do not create a contiguous profile of the three-dimensional solid, but rather each set of curves is independently rotated into a two-dimensional plane of interest. To graphically represent a full envelope of the three-dimensional solid, intersecting curves must be extended through the solid at selected



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angles or potential areas of the solid will not be graphically profiled. Such drafting programs require large amounts of disk storage space to store the numerous intersecting curves. Furthermore, such programs are time-consuming to execute because of the large amount of computations created as a result of the numerous intersections.

## BRIEF SUMMARY OF THE INVENTION

In an exemplary embodiment, a two-dimensional profile curve of a computer representation of a three-dimensional solid model is automatically generated. More specifically, and in one embodiment, a two-dimensional representation is created with a computer executing a profile curve generator without creating separate intersection lines that extend through the three-dimensional solid. The profile curve generator queries the three-dimensional solid to identify faces on the three-dimensional solid. The query of the three-dimensional solid begins after a revolved face is identified as a seed face. The query process continues until all the faces have been queried and processing returns to the seed face. As each revolved face is located, internal edge loops disposed within the face are ignored and a representative curve for the face is created in the two-dimensional plane.

The computer executing the algorithm is programmed to terminate the algorithm if a face edge is not identified which satisfies internal constraints programmed within the algorithm. The computer is also programmed to terminate the execution of the algorithm if the curve generated is not continuous. As a result, the algorithm enables the computer to generate contiguous curves and accurate two-dimensional representations of three-dimensional solids in a more cost-efficient and less time-consuming manner in comparison to known profile curve generators.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a profile curve generator system;

Figure 2 is a flowchart of an algorithm for use with the profile curve generator system shown in Figure 1; and

Figure 3 is a flow chart of an equivalent face curve generator for use with the algorithm shown in Figure 2.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is block diagram of a profile curve generator system 10 for automatically generating two-dimensional profile curves of three-dimensional solid models. Profile curve generator system 10 includes a server system 12 and a plurality of client systems 14 connected to server system 12. In one embodiment, client system 14 includes a computer (not shown) including a web browser, a central processing unit (CPU), a random access memory (RAM), an output device, for example a monitor, a mass storage device, and an input device, for example a keyboard or a mouse. Server system 12 is accessible to client system 14 via the Internet. Client system 14 is interconnected to the Internet through many interfaces including dial-in-connections, cable modems, special high-speed ISDN lines, and networks, such as local area networks (LANs) or wide area networks (WANs). In one embodiment, client system 14 includes any client system capable of interconnecting to the Internet including a web-based phone or other web-based connectable equipment. Server system 12 is also connected to a mass storage device 18. Mass storage device 18 is accessible by potential users through client system 14.

Figure 2 is a flowchart 80 of an algorithm 82 for use with profile curve generator system 10 (shown in Figure 1). Algorithm 82 is stored in mass storage device 18 (shown in Figure 1) and is accessible to a potential user through client system 14 (shown in Figure 1) to generate a single equivalent profile curve (not shown) for each revolved face (not shown) of a three-dimensional solid (not shown) in a two-dimensional plane (not shown). The three-dimensional solids are introduced to algorithm 82 in an electronic format that is compatible with computer aided design (CAD) type programs. Furthermore, the three-dimensional solids are primarily revolved and have cyclic symmetry about an axis of rotation (not shown). In one embodiment, the three-dimensional models include features (not shown) that are not continuously swept through 360 degrees.

In accordance with algorithm 82, no intersecting planes within the three-dimensional body being sectioned are created. Rather, in lieu of such intersections, a single equivalent profile curve for each revolved face in the two-dimensional plane is created. Initially, a user selects 100 a three-dimensional solid to be profiled and the selection is entered into client system 14. Server system 12 accesses algorithm 82 from mass storage device 18 and a loop-wise sequence is executed to query 110 the edges of the three-dimensional solid. The loop-wise sequence ensures that a contiguous path of profile curves is created and identifies a circular edge that is a revolved edge. A circular edge that is aligned with respect to the three-dimensional solid axis of rotation is considered a revolved edge. Such edges border faces and the three-dimensional solid may include any or all of five different revolved faces including: toroidal, conical, planar, cylindrical, or revolved-spline.

It is then determined 120 if such a circular edge was identified when the loop-wise sequence was executed. Such a circular edge is known as a seed revolved edge and is disposed on a seed face. If a circular edge is not identified, an error is reported 122 to the user and algorithm 82 terminates 124. If a circular edge is identified, that specific circular edge is given an identifier "S" and an empty traced list is initialized 130. The traced list identifies which faces of the three-dimensional solid have been processed and traversed. As algorithm 82 is executed, the traced list is continuously populated with any faces traversed.

A radius, identified as R1, and an axial position, identified as Z1, of the curved edge S are queried 140. The curved edge S is set 150 to a current edge identifier E1 and a loop 152 is executed. The three-dimensional solid is then queried 160 to start the execution of loop 152 and to identify a revolved face adjacent current edge E1 that has not been traversed according to the set of faces stored in the traced list.

A determination 170 is made whether an additional face is found. If such a face is found, the face is queried 180 and data from the face (i.e., torus radii, cone angle, etc.) relating to one of the five types of faces, toroidal, conical, planar, cylindrical, or revolved-spline, is added 190 to the traced list. As data from the face is

collected and added 190 to the traced list, an external set of edge curves for the face are identified. The external set of edge curves for the face are then cycled 200 to locate a revolved edge, identified as E2, disposed at the furthest radial, identified as R2, and axial location, identified as Z2, from edge E1. A query 210 confirms the location of the furthest radial, R2, and the axial location Z2.

A subroutine (described in more detail below) is executed to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2). The equivalent face curve is added 230 to a string of profile curves previously generated. The string of curves are bounding and will eventually define the revolved profile. The computer executing algorithm 82 is programmed to assume that every face has exactly two circular trimming edges which define the end points, i.e., a beginning and an end, of the equivalent curve, and essentially define the maximum envelope of that particular face.

After the equivalent face curve is added 230 to the string of curves, the beginning of the next curve to be generated is set 240. To set 240 the beginning of the next curve, algorithm 82 changes the beginning of the next curve to represent the end of the curve just created 220. Additionally, the current edge, E1, is also set to E2 and loop 152 is repeated to query 160 the three-dimensional solid to identify a revolved face adjacent current edge E1 that has not been traversed according to the set of faces stored in the traced list.

The computer executing algorithm 82 continues executing loop 152 until a determination 170 is reached based on the traced list that the three-dimensional solid includes no additional adjacent resolved faces. If no additional faces are found, the execution of loop 152 ceases, and a determination 300 if the created string of curves is continuous is made. If the string of curves is continuous, a two-dimensional surface is created 310 and algorithm 82 is terminated 124. If the string of curves is determined 300 non-continuous, the curves are deleted 320 and an error is reported 330 to the user prior to algorithm 82 terminating 124.

Figure 3 is a flow chart of a subroutine 400 for use with algorithm 82 (shown in Figure 2) to create 220 (shown in Figure 2) an equivalent face curve. When algorithm 82 is executed, a query 210 (shown in Figure 2) confirms the location of furthest radial, R2, and the axial location Z2 with respect to edge E1. A subroutine 400 is executed to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2). After receiving 410 the points (R1, Z1) and (R2, Z2) from loop 152 (shown in Figure 2), a subroutine 400 is executed to determine which of the five types of faces, toroidal, conical, planar, cylindrical, or revolved-spline, is defined between points points (R1, Z1) and (R2, Z2) is made. If a face is determined 420 to be toroidal, an arc extending through points (R1, Z1) and (R2, Z2) and including a torus minor radius is created 430. The arc data is introduced to loop 152 to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2).

If the face is not determined 420 to be toroidal, subroutine 400 is executed to determine 440 if the face is conical, cylindrical, or planar. If the face is conical, cylindrical, or planar, a line extending through points (R1, Z1) and (R2, Z2) and having a slope substantially equal to a slope of the specific face being profiled is created 450. The line data is introduced to loop 152 to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2).

If the face is not determined to be conical, cylindrical, or planar, subroutine 400 is executed to determine 460 if the face is a spline revolution. If the face is a spline revolution, algorithm 82 extracts 470 the resolved spline, and transforms the resolved spine to a two-dimensional plane. The resolved two-dimensional spline is then trimmed 480 to extend between points (R1, Z1) and (R2, Z2) and the data is introduced to loop 152 to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2).

The above-described algorithm is cost-effective and highly reliable. The computer executing the algorithm creates a single equivalent profile curve for each revolved face of a three-dimensional solid in a two-dimensional plane without extending intersecting planes through the three-dimensional body being sectioned. Additionally, a detailed and complete representation of the full envelope of the three-

dimensional solid is generated. As a result, an algorithm is provided which when programmed into a computer, permits the computer to produce two-dimensional planar representations of three-dimensional solids in a cost-effective and reliable manner.

While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.

WHAT IS CLAIMED IS:

1. A method for creating a two-dimensional representation of a revolved three-dimensional solid, said method comprising the steps of:

selecting the three-dimensional solid for which the associative two-dimensional section is to be generated; and

generating a single equivalent profile curve for each revolved face of the three-dimensional solid in a two-dimensional plane.

2. A method in accordance with Claim 1 wherein the three-dimensional solid includes a plurality of adjacent faces, said step of generating a single equivalent curve further comprises the steps of:

identifying a seed revolved edge on the three-dimensional solid selected; and

querying the three-dimensional solid for revolved faces adjacent to the seed revolved edge.

3. A method in accordance with Claim 2 wherein said step of querying the three-dimensional solid further comprises the steps of:

creating a trace list including each face identified and traversed while querying the three-dimensional solid; and

querying the solid with a loop-wise sequence to generate a contiguous path of profile curves.

4. A method in accordance with Claim 3 wherein the three-dimensional solid includes one of a torodial and spherical face, said step of generating a single equivalent profile curve further comprising the step of creating an arc as an equivalent profile curve.

5. A method in accordance with Claim 4 wherein the three-dimensional solid includes one of a conical, planar, or cylindrical face, said step of generating a single equivalent profile curve further comprising the step of creating a line as an equivalent profile curve.

6. A method in accordance with Claim 5 wherein the three-dimensional solid includes a revolved-spline face, said step of generating a single equivalent profile curve further comprising the step of creating a spline as an equivalent profile curve.

7. An apparatus for generating a two-dimensional representation of a three-dimensional solid, said apparatus comprising a processor programmed to generate a single equivalent profile curve for each revolved face in a two-dimensional plane.

8. An apparatus in accordance with Claim 7 wherein the three-dimensional solid has cyclic symmetry, said processor further programmed to generate the two-dimensional representation without generating intersection lines within the three-dimensional solid.

9. An apparatus in accordance with Claim 8 wherein said processor further programmed to follow a loop-wise sequence to create a contiguous path of profile curves.

10. An apparatus in accordance with Claim 9 wherein said processor further programmed to identify a seed revolved edge bordering a face and to query the three-dimensional solid from the revolved edge to each adjacent face to circumscribe the three-dimensional solid.

11. An apparatus in accordance with Claim 10 wherein the three-dimensional solid includes one of a torodial and spherical face, said processor further programmed to generate an arc.

12. An apparatus in accordance with Claim 10 wherein the three-dimensional solid includes one of a conical, planar, and cylindrical face, said processor further programmed to generate a line.

13. An apparatus in accordance with Claim 10 wherein the three-dimensional solid includes a revolved-spline face, said processor further programmed to generate a spline.

14. A system for creating a two-dimensional representation of a three-dimensional solid, said system comprising;

a client system comprising a browser;

a data storage device for storing information relevant to a plurality of users; and

a server system configured to be coupled to said client system and said data storage device, said server system further configured to generate a single equivalent curve for each revolved face of the three-dimensional solid in a two-dimensional plane.

15. A system in accordance with Claim 14 wherein said server system further configured to follow a loop-wise sequence to create a contiguous path of profile curves.

16. A system in accordance with Claim 15 wherein said server system further configured to create the two-dimensional representation without generating intersection lines extending through the three-dimensional solid.

17. A system in accordance with Claim 16 wherein said server system further configured to identify a seed revolved edge.

18. A system in accordance with Claim 17 wherein the three-dimensional solid has cyclic symmetry, said server system further configured to query the three-dimensional solid from the identified seed revolved edge through each subsequent adjacent face until returning to the seed revolved edge.

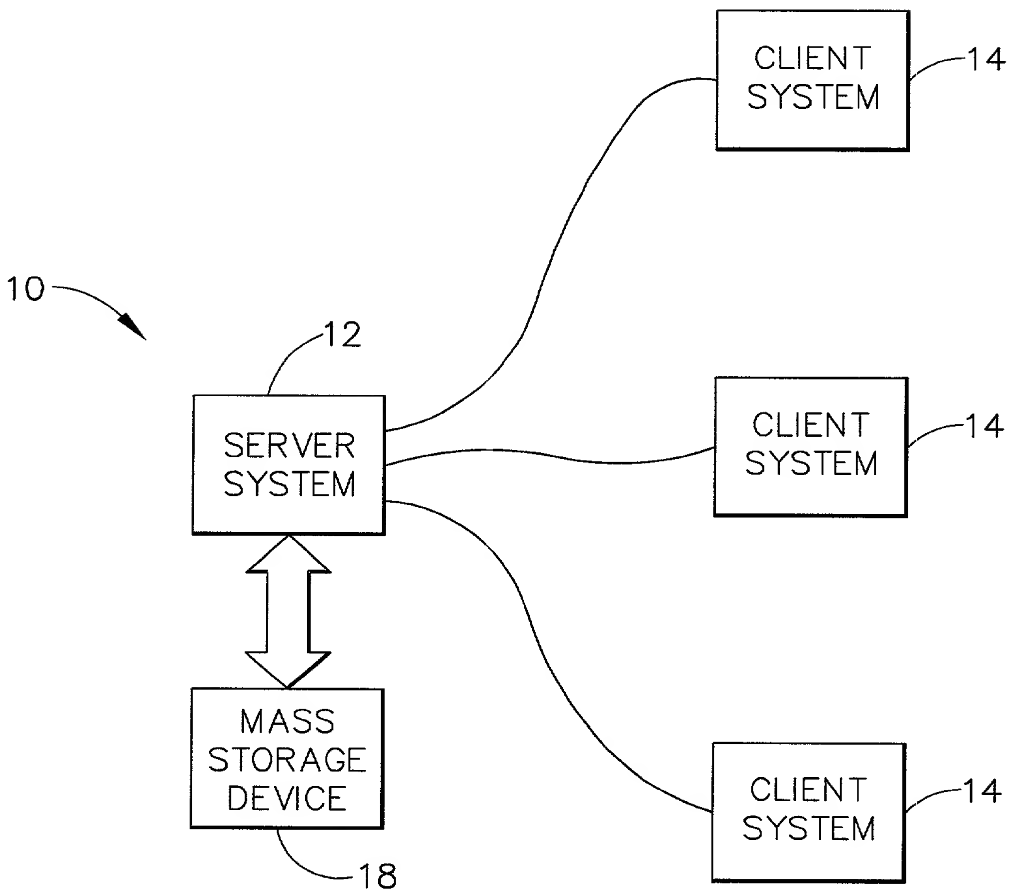
19. A system in accordance with Claim 18 wherein the three-dimensional solid has one of a torodial face and a spherical face, said server system further configured to generate an arc.

20. A system in accordance with Claim 19 wherein the three-dimensional solid has one of a conical face, a planar face, and a cylindrical face, said server system further configured to generate a line.

# METHODS AND SYSTEMS FOR GENERATING PROFILE CURVES OF SOLID MODELS

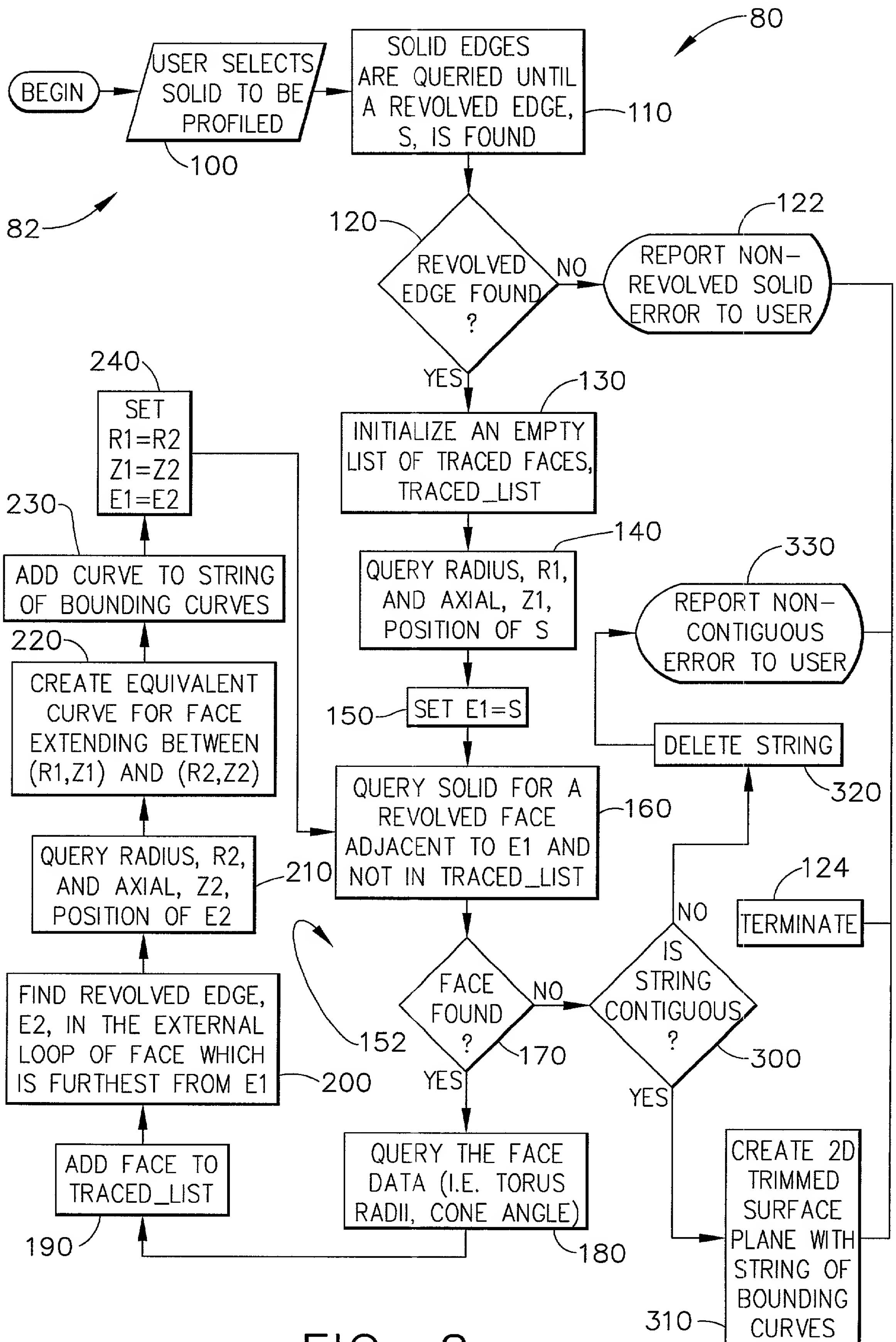
## ABSTRACT OF THE DISCLOSURE

An algorithm programmed into a computer permits the computer to automatically generate a two-dimensional profile curve of an electronically represented three-dimensional solid model without creating separate intersecting planes extending through the three-dimensional solid. The computer is configured to query the three-dimensional solid to identify faces on the three-dimensional solid. The query of the solid begins after a face edge is identified as a seed face and continues from the identified face to each adjacent revolved face circumscribing the solid. As each revolved face is located, a representative curve for the face is created in the two-dimensional plane.



10
12
SERVER SYSTEM
MASS STORAGE DEVICE
18
CLIENT SYSTEM
14
CLIENT SYSTEM
14
CLIENT SYSTEM
14


FIG. 1



80
82
BEGIN
USER SELECTS SOLID TO BE PROFILED
100
SOLID EDGES ARE QUERIED UNTIL A REVOLVED EDGE, S, IS FOUND
110
120
REVOLVED EDGE FOUND ?
NO
YES
122
REPORT NON-REVOLVED SOLID ERROR TO USER
130
INITIALIZE AN EMPTY LIST OF TRACED FACES, TRACED_LIST
140
QUERY RADIUS, R1, AND AXIAL, Z1, POSITION OF S
150
SET E1=S
160
QUERY SOLID FOR A REVOLVED FACE ADJACENT TO E1 AND NOT IN TRACED_LIST
170
FACE FOUND ?
NO
YES
180
QUERY THE FACE DATA (I.E. TORUS RADII, CONE ANGLE)
190
ADD FACE TO TRACED_LIST
200
FIND REVOLVED EDGE, E2, IN THE EXTERNAL LOOP OF FACE WHICH IS FURTHEST FROM E1
210
QUERY RADIUS, R2, AND AXIAL, Z2, POSITION OF E2
220
CREATE EQUIVALENT CURVE FOR FACE EXTENDING BETWEEN (R1,Z1) AND (R2,Z2)
230
ADD CURVE TO STRING OF BOUNDING CURVES
240
SET R1=R2 Z1=Z2 E1=E2
152
300
IS STRING CONTIGUOUS ?
NO
YES
310
CREATE 2D TRIMMED SURFACE PLANE WITH STRING OF BOUNDING CURVES
320
DELETE STRING
330
REPORT NON-CONTIGUOUS ERROR TO USER
124
TERMINATE


FIG. 2

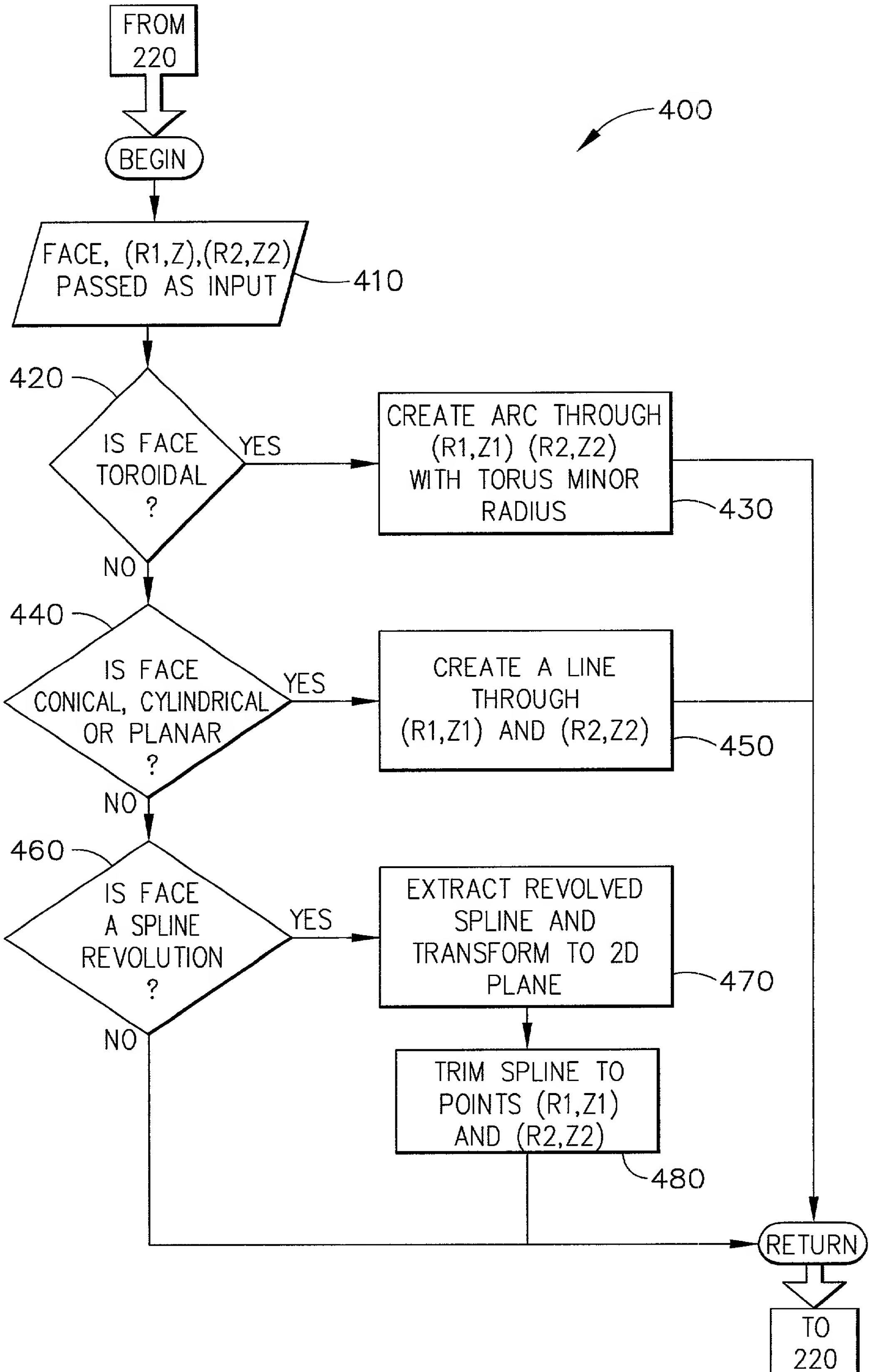

FROM 220
BEGIN
400
FACE, (R1,Z),(R2,Z2) PASSED AS INPUT
410
420
IS FACE TOROIDAL ?
YES
CREATE ARC THROUGH (R1,Z1) (R2,Z2) WITH TORUS MINOR RADIUS
430
NO
440
IS FACE CONICAL, CYLINDRICAL OR PLANAR ?
YES
CREATE A LINE THROUGH (R1,Z1) AND (R2,Z2)
450
NO
460
IS FACE A SPLINE REVOLUTION ?
YES
EXTRACT REVOLVED SPLINE AND TRANSFORM TO 2D PLANE
470
NO
TRIM SPLINE TO POINTS (R1,Z1) AND (R2,Z2)
480
RETURN
TO 220

FIG. 3

# DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

| Docket Number |
|---|
| 13DV13386 |

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

-----METHODS AND SYSTEMS FOR GENERATING PROFILE CURVES OF SOLID MODELS-----

the specification of which

☒ is attached hereto
OR
☐ was filed on ______ as United States Application Number or PCT International Application Number ______
and was amended on ______ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37 Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119 (a)-(d) or §365 (b) of any foreign application(s) for patent or inventor's certificate, or §365 (a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

**PRIOR FOREIGN APPLICATION(s)**

| (Number) | (Country) | (Day/Month/Year Filed) | Priority Claimed |
|---|---|---|---|
| | | | ☐ Yes ☐ No |
| | | | ☐ Yes ☐ No |

☐ Additional foreign application numbers are listed on a supplemental priority data sheet attached hereto.

I hereby claim the benefit under Title 35, United States Code §119 (e) of any United States provisional application(s) listed below.

| (Application Number) | (Filing Date) |
|---|---|
| | |

☐ Additional provisional application numbers are listed on a supplemental priority data sheet attached hereto.

I hereby claim the benefit under Title 35, United States Code §120 of any United States Application(s), or §365 (c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

| (Application Number) | (Filing Date) | (Status - patented, pending, abandoned) |
|---|---|---|
| | | |
| | | |

I hereby appoint the registered practitioners associated with Customer Number 006111 to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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First Name Middle Name Last Name

Signature: ____ Date ____

Residence: ____ Citizenship: ____
City and State

Post Office Address: ____

---

THIRD JOINT INVENTOR:

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First Name Middle Name Last Name

Signature: ____ Date ____

Residence: ____ Citizenship: ____
City and State

Post Office Address: ____

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FOURTH JOINT INVENTOR:

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First Name Middle Name Last Name

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City and State

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